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# TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER: 9794353-014

U S APPLICATION NO (If known, see 37 CFR 1 5): 09/787212

| INTERNATIONAL APPLICATION NO. | INTERNATIONAL FILING DATE | PRIORITY DATE CLAIMED |
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| PCT/JP00/04743 | (14.07.00) 14 July 2000 | (14.07.99) 14 July 1999 |

TITLE OF INVENTION: METHOD FOR FABRICATING A FRACTAL STRUCTURE

APPLICANT(S) FOR DO/EO/US: UGAJIN, Ryuichi; KUROKI, Yoshihiko; ISHIBASHI, Akira; HIRATA, Shintaro

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. [X] The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is attached hereto (required only if not communicated by the International Bureau).
   b. [ ] has been communicated by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [X] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. [X] is attached hereto.
   b. [ ] has been previously submitted under 35 U.S.C. 154(d)(4).
7. [ ] Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are attached hereto (required only if not communicated by the International Bureau).
   b. [ ] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). unexecuted
10. [ ] An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Items 11 to 20 below concern document(s) or information included:**

11. [X] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [ ] A FIRST preliminary amendment.
14. [ ] A SECOND or SUBSEQUENT preliminary amendment.
15. [ ] A substitute specification.
16. [ ] A change of power of attorney and/or address letter.
17. [ ] A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. [ ] A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. [ ] A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. [X] Other items or information:
   Int'l Search Report w/cited references
   Formal Drawings

| U.S. APPLICATION NO. (if known, see 37 CFR 1.5) | INTERNATIONAL APPLICATION NO | ATTORNEY'S DOCKET NUMBER |
|---|---|---|
| 09/787212 | PCT/JP00/04743 | 9794353-014 |

| 21. [x] The following fees are submitted: | CALCULATIONS | PTO USE ONLY |
|---|---|---|
| **BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):** | | |
| Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO . . . . . . . . . . . **$1000.00** | | |
| International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO . . . . . . . . **$860.00** | | |
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| International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) . . . . . . . . . **$690.00** | | |
| International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) . . . . . . . . . . . . . . . **$100.00** | | |
| **ENTER APPROPRIATE BASIC FEE AMOUNT =** | $ 860.00 | |
| Surcharge of **$130.00** for furnishing the oath or declaration later than [x] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)). | $ 130.00 | |

| CLAIMS | NUMBER FILED | NUMBER EXTRA | RATE | | |
|---|---|---|---|---|---|
| | | | | $ | |
| Total claims | 11 - 20 = | | x **$18.00** | $ | |
| Independent claims | 1 - 3 = | | x **$80.00** | $ | |
| MULTIPLE DEPENDENT CLAIM(S) (if applicable) | | | + **$270.00** | $ | |
| **TOTAL OF ABOVE CALCULATIONS =** | | | | $ 990.00 | |
| [ ] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2. + | | | | $ | |
| **SUBTOTAL =** | | | | $ | |
| Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). | | | | $ | |
| **TOTAL NATIONAL FEE =** | | | | $ 990.00 | |
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**NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.**

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DESCRIPTION

# METHOD FOR FABRICATING A FRACTAL STRUCTURE

## Technical Field

This invention relates to a method for fabricating a fractal structure, especially suitable for application to constructing a complex network such as neural network, for example.

## Background Art

Conventional Neuman computers have exercised their great power in computers configured to sequentially execute specific algorithms and have supported modern scientific technologies. In order to design CPU of such a computer, a complicated electronic circuit has to be produced and progressively optimized by executing its simulation. As its design tool, a CAD system for making a complicated electronic circuit is indispensable.

In recent years, information processing learning from brains, such as neural network model, has been widely researched with a hope of realization as exercising its power in pattern recognition. In case a neural network model is practically applied in form of a device, it is preferable to realize a network such as neural network of a brain in form of a certain system. Following such a plan, experiments are being conducted toward artificially making nerves for

living bodies, and their future development is being expected.

Nerve cells of brains individually have complicated tree-like projections to form a fractal structure. Such fractal elements grow while interacting with each other, and make up a complicated brain neural network.

In order to simulate the function of a preferable network, a technique for creating such a brain neural network is indispensable. That is, there is a strong demand for a technique for making a complicated network, which corresponds to a CAD system that has been indispensable for conventional Neuman computers. However, there are no conventional techniques that make up a structure coupling a plurality of fractal elements while controlling their fractal nature.

It is therefore an object of the invention to provide a method for making a fractal structure, which can make a complicated network like a neural network easily in a well-controlled manner.

A further object of the invention is to provide a method for making a fractal structure, which can control the coupling mode among different fractal structures and can make complicated networks with a more variety of structures such as neural networks easily in a well-controlled manner.

Disclosure of Invention

The Inventors made active studies toward solution of the above-mentioned problem, and as a result, found that it would be possible to make complicated networks such as neural networks by growing fractal structures from different start sites and have them interact with each other. Additionally, the Inventors found that it would be possible to control the coupling mode among fractal structures by introducing anisotropy into spaces for growing the fractal structures. Thus the Inventors have reached the present invention.

In order to solve the above mentioned subject, according to the invention, there is provided a method for fabricating a fractal structure characterized in growing fractal structures from a plurality of start sites, respectively, while having said fractal structures interact with each other, to form fractal structures coupled to each other.

In the present invention, universal interaction among element fractal structures is controlled against fluctuation in growth process of fractal structures from individual start sites.

In the present invention, growth rate from a specific start site among a plurality of start sites is determined by the probability that a material reaches a portion already grown from a remote position due to a diffusion process and the probability that a growth

promotion factor reaches the portion already grown from portions grown from the other start sites due to a diffusion process. The growth rate is proportional to the product of the power function of the probability that the material reaches the portion already grown from a remote position due to a diffusion process and the power function of the probability that the growth promotion factor reaches the portion already grown from portions grown from the other start sites due to a diffusion process. Further, in the present invention, fractal property of a structure, its self-similarity, complexity or number of coupling is typically controllable parametrically. More specifically, relative potential determining diffusion of a growth promotion factor among individual fractal structures grown from a plurality of start sites is appropriately adjusted relative to a site at infinity, and thereby, fractal property, self-similarity, complexity or number of coupling of a structure is controllable substantially parametrically.

In the present invention, anisotropy may be introduced into the space in which the fractal structure is grown. More specifically, for example, in case the growth rate from a specific start site among a plurality of start sites is determined by the probability that a material reaches a portion already grown from a remote position due to a diffusion process and the probability that a growth promotion factor reaches the portion already grown from

portions grown from the other start sites due to a diffusion process, diffusion coefficient in the diffusion process in the space for growing the fractal structure has an anisotropy. Also in this case, fractal property of a structure, its self-similarity, complexity or number of coupling is typically controllable parametrically. The anisotropy is not limited to the anisotropy of the diffusion coefficient, but may be, for example, an anisotropy of the dielectric constant in the space for growing the fractal structure.

According to the invention having the configuration summarized above, by growing fractal structures from a plurality of start sites while having individual structures frown from their respective start sites to interact with each other to form fractal structures coupled to each other, it is possible to fabricate a network made up of elements individually having fractal complexity easily in a well-controlled manner.

Further, in case an anisotropy is introduced into the space for growing the fractal structure in, when individual fractal structures grow from their respective start sites while interacting with each other to form fractal structures coupled to each other, the response produced inside a single fractal structure is affected by a stronger nonlinear effect from coupling of different fractal structures. Then, remarking the number of sites where different fractal structures contact as an index of control

of the coupling mode among fractal structures, nonlinearity can be controlled by controlling the number of those sites.

Brief Description of Drawings

Fig. 1 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 2 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 3 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 4 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 5 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 6 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 7 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 8 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 9 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 10 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 11 is a schematic diagram that shows a result of

simulation for fabricating a neural network according to the invention; Fig. 12 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 13 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 14 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 15 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 16 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 17 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 18 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 19 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 20 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 21 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 22 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 23 is a schematic diagram that shows a result of simulation for fabricating a neural

network according to the invention; Fig. 24 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 25 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 26 is a schematic diagram that shows a result of simulation for fabricating a neural network according to the invention; Fig. 27 is a schematic diagram that shows changes of normal deviation of distribution in the z-axis direction upon making a neural network by introducing an anisotropy merely in the z-axis direction on a three-dimensional lattice according to the invention; Fig. 28 is a schematic diagram that shows changes in number of adjacent sites among fractal figures for a growth step during fabrication of a neural network by introducing an anisotropy merely in the z-axis direction on a three-dimensional lattice according to the invention; Fig. 29 is a schematic diagram that shows a result of simulation for growth of a coupled fractal network according to the invention; Fig. 30 is a schematic diagram that shows a result of simulation for growth of a coupled fractal network according to the invention; Fig. 31 is a schematic diagram that shows a result of simulation for growth of a coupled fractal network according to the invention; Fig. 32 is a schematic diagram that shows a result of simulation for growth of a coupled fractal network according to the invention; Fig. 33 is a schematic diagram that shows a result of simulation for

growth of a coupled fractal network according to the invention; Fig. 34 is a schematic diagram that shows a result of simulation for growth of a coupled fractal network according to the invention; Fig. 35 is a schematic diagram that shows changes in distance between centers of gravity for a growth step in simulation of growth of a coupled fractal network according to the invention; Fig. 36 is a schematic diagram that shows changes in distance between centers of gravity for a growth step in simulation of growth of a coupled fractal network according to the invention; Fig. 37 is a schematic diagram that shows changes in distance between centers of gravity for a growth step in simulation of growth of a coupled fractal network according to the invention; Fig. 38 is a schematic diagram that shows changes in distance between centers of gravity for a growth step in simulation of growth of a coupled fractal network according to the invention; Fig. 39 is a schematic diagram that shows changes in distance between centers of gravity for a growth step in simulation of growth of a coupled fractal network according to the invention; and Fig. 40 is a schematic diagram that shows changes in distance between centers of gravity for a growth step in simulation of growth of a coupled fractal network according to the invention.

Best Mode for Carrying Out the Invention

Explained below are embodiments of the invention with reference to the drawings.

(1) Dielectric breakdown model

First explained is a method of making a singular fractal figure (for example, a figure such as tree-like projections) ((1) A. Erzan, L. Pietronero, A. Vespignani, Rev. Mod. Phys. 67, 545(1995); (2) T.A. Witten, Jr. and L.M. Sander, Phys. Rev. Lett. 47, 1400(1984); Phys. Rev. B 27, 5686(1983)). This method is a dielectric breakdown model proposed by Niemeyer et al. ((3) L. Niemeyer, L. Pietronero, H.J. Wiesmann, Phys. Rev. Lett. 52, 1033(1984)).

As an example, a tetragonal lattice S in a two-dimensional space is defined, and a scalar potential field $\phi(i, j)$ is defined on a lattice site $(i_1, i_2, i_3) \in S$. This is called an electric potential. Let this electric potential follow a Laplace equation:

$$\triangle\phi(i,j) = 0 \qquad (1)$$

The figure $T_n$ defined therefrom is a set of lattice sites on a two-dimensional lattice. $T_0$ consists of (0, 0) alone, and $T_{n+1}$ is created by sequentially adding one lattice site to $T_n$ by the following rule.

Let the electric potential of each site contained in $T_n$ be 1 and the electric potential at a site at infinity be 0. That is,

$$\phi(i,j) = 0 \quad \text{when} \quad (i,j) \longrightarrow \infty \qquad (2)$$

$$\phi(i,j) = 1 \quad \text{when} \quad (i,j) \in T_n \tag{3}$$

Equation (1) is solved under that boundary condition, and electric potential of each lattice site is determined. The lattice site to be added to $T_n$ to form $T_{n+1}$ is not included in $T_n$, and it is selected from a set $U_n$ of lattice sites closest to $T_n$. The number of lattice sites contained in $U_n$ is written as $N_n$.

For each site contained in $U_n$ $(i_m, j_m)$ (where m=1, 2, ..., $N_n$), its electric field intensity is defined as:

$$E_m(\alpha) = |\phi(i_m, j_m) - 1|^\alpha \tag{4}$$

The probability that a site $(i_m, j_m)$ in $U_n$ is proportional to its electric field intensity $E_m(\alpha)$. That is, the probability is:

$$p_m(\alpha) = \frac{E_m(\alpha)}{\sum_{j=1}^{N_n} E_j(\alpha)} \tag{5}$$

By repeating the above operation, $T_n$ is formed progressively. An ideal fractal will be the infinitely repeated extreme set:

$$T_\infty = \lim_{n\to\infty} T_n \tag{6}$$

In case of $\alpha$=1, the above coincides with the result of

generation of a figure by diffusion limited aggregation ((2) T.A. Witten, Jr. and L.M. Sander, Phys. Rev. Lett. 47, 1400(1984)); Phys. Rev. B 27, 5686(1983)).

(2) Fractals that grow while interacting with each other

Defined below are fractals that grow while interacting with each other (interacting fractals), i.e. a coupled-fractal network. As an example, fractals made up of $N_c$ species are taken on a tetragonal lattice S in a two-dimensional space. A scalar potential field $\phi(i, j)$ is defined on a lattice site $(i_1, i_2, i_3) \in S$, and this is called a potential. Then, $\psi^{(1)}(i, j)$, $\psi^{(2)}(i, j)$, ..., $\psi^{(Nc)}(i, j)$ are also defined. They satisfy the differential equations:

$$\Delta\phi(i,j) = 0 \tag{7}$$

$$\Delta\psi^{(1)}(i,j) = 0 \tag{8}$$

$$\Delta\psi^{(2)}(i,j) = 0 \tag{9}$$

$$\vdots$$

$$\Delta\psi^{(N_c)}(i,j) = 0 \tag{10}$$

The figure $T_n$ defined therefrom is a set of lattice sites on a two-dimensional lattice, and respective lattice sites are classified into $N_c$ species. That is,

$$T_n = \bigcup_{j=1}^{N_c} Q_n^{(j)} \tag{11}$$

and respective species are exclusive from each other. That is,

$$Q_n^{(j)} \bigcap Q_n^{(k)} = \emptyset \text{ if } j \neq k \tag{12}$$

$Q_0^{(k)}$ consists of a single lattice site $(i_{\text{ini}}^{(k)}, j_{\text{ini}}^{(k)})$ exclusively, and $T_{n+1}$ is created by sequentially adding one lattice site to $T_n$ by the following rule. First, Equation (7) is solved under the boundary conditions:

$$\phi(i,j) = 0 \quad \text{when} \quad (i,j) \longrightarrow \infty \tag{13}$$

$$\phi(i,j) = 1 \quad \text{when} \quad (i,j) \in T_n \tag{14}$$

and potential of each lattice site is determined. Further, Equations (8) through (10) are solved under the boundary conditions:

$$\psi^{(k)}(i,j) = 0 \quad \text{when} \quad (i,j) \longrightarrow \infty \tag{15}$$

$$\psi^{(k)}(i,j) = 1 \quad \text{when} \quad (i,j) \in Q_n^{(k)} \tag{16}$$

$$\psi^{(k)}(i,j) = -1 \quad \text{when} \quad (i,j) \in Q_n^{(l)} \ (k \neq l) \tag{17}$$

and $\psi^{(k)}(i,j)$ is determined. The lattice site to be added to $T_n$ to form $T_{n+1}$ is not included in $T_n$, and it is selected from a set $U_n^{(k)}$ of lattice sites closest to $Q_n^{(k)}$.

The number of lattice sites contained in $U_n^{(k)}$ is written as $N_n^{(k)}$. That is, the lattice site to be added to $T_n$ is selected from the following set:

$$U_n = \bigcup_{k=1}^{N_c} U_n^{(k)} \tag{18}$$

and the number of lattice sites contained in the set, i.e. the number of candidates, is:

$$N_n = \sum_{k=1}^{N_c} N_n^{(k)} \tag{19}$$

For each site $(i_m^{(k)}, j_m^{(k)})$ (m=1, 2, ..., $N_n^{(k)}$) contained in $U_n^{(k)}$, intensity of its electric field is defined as:

$$E_m^{(k)}(\alpha,\beta) = |\phi(i_m^{(k)}, j_m^{(k)}) - 1|^\alpha \times |\psi^{(k)}(i_m^{(k)}, j_m^{(k)}) - 1|^\beta \tag{20}$$

The probability that a site $(i_m^{(k)}, j_m^{(k)})$ in $U_n$ is selected is proportional to intensity of its electric field $E_m^{(k)}(\alpha,\beta)$. That is, the probability is:

$$p_m^{(k)}(\alpha,\beta) = \frac{1}{\Delta} E_m^{(k)}(\alpha,\beta) \tag{21}$$

$$\Delta = \sum_{k=1}^{N_c} \sum_{j=1}^{N_n^{(k)}} E_j^{(k)}(\alpha,\beta) \tag{22}$$

By repeating the above-mentioned procedures, $T_n$ is formed progressively.

Here is given a physical (or physiologic) interpretation regarding the above model. $\phi(i, j)$ provides the probability of arrival of a growth material $S_{rc}$ transported from a remote site by diffusion at a region permitting growth from interpretation of the dielectric breakdown model. On the other hand, $\psi_k(i, j)$ provides the probability of arrival of any substance X transported to a region permitting growth of the k-th species from portions where species except for the k-th species have been already grown. The assumption that the probability that growth of the k-th species occurs is proportional to the product means the assumption that the growth occurs only when both the growth material $S_{rc}$ and the substance X have arrived. That is, here is assumed the situation in which growth occurs by adhesion of the growth material $S_{rc}$ to the portion where the k-th species has already grown with the aid of an adhesive substance X. Of course, it means a reaction that is rate-determined by adhesion interposing the adhesive substance X. In an alternative interpretation, it is possible to consider that $\phi(i, j)$ provides the probability of arrival of the growth material $S_{rc}$ transported by diffusion from a remote site to the region where it can grow, similarly to the above interpretation whereas $\psi_k(i, j)$ provided the potential at the position of the k-th species, and the

probability that growth of the k-th species occurs is proportional to the product of the probability of arrival of the growth material $S_{rc}$ and the intensity of the electric field.

Explained below is a specific example of the method of fabricating a neural network based on the model shown in (2) above. One of results of simulation is shown in Fig. 1. In this simulation, $(\alpha, \beta)=(0.5, 1.0)$ was used, and 4000-step growth from four sites was conducted. In Fig. 2, using the same $(\alpha, \beta)$, 3000-step growth from three sites was conducted. By changing parameters, various figures can be created. If $\alpha$ corresponding to the growth material transported from a remote site is large, then respective elements tend to spread. If $\beta$ corresponding to the adhesive substance nearby is large, the coupling becomes dense. Figures upon executing 2000-step growth from two sites by changing $(\alpha, \beta)$ are shown in Figs. 3 through 7. In Fig. 3, similarly to the above two examples, $(\alpha, \beta)=(0.5, 1.0)$ was used. Examples increasing $\beta$ from that are shown in Figs. 4 through 6. $(\alpha, \beta)=(0.5, 1.5)$ was used in Fig. 4, $(\alpha, \beta)=(0.5, 2.0)$ was used in Fig. 5, and $(\alpha, \beta)=(0.5, 2.5)$ was used in Fig. 6, respectively. It is appreciated that the coupling becomes dense as $\beta$ increases. On the other hand, if the relation in value between $\alpha$ and $\beta$ is reversed, growth tends to proceed spreading remoter as shown in Fig. 7 [$(\alpha, \beta)=(1.0, 0.5)$]. In this manner, by changing the parameters $\alpha$ and $\beta$, various neural network structures can be produced

while controlling properties of figures.

(3) Extended interacting fractals

Extended interacting fractals, i.e. a coupled-fractal network, are defined below. As an example, fractals made up of $N_c$ species are taken on a tetragonal lattice S in a two-dimensional space. A scalar potential field $\phi(i, j)$ is defined on a lattice site $(i, j) \in S$, and this is called a potential. Then, $\psi^{(1)}(i, j)$, $\psi^{(2)}(i, j)$, ..., $\psi^{(Nc)}(i, j)$ are also defined. They satisfy the differential equations:

$$\Delta\phi(i,j) = 0 \tag{23}$$

$$\Delta\psi^{(1)}(i,j) = 0 \tag{24}$$

$$\Delta\psi^{(2)}(i,j) = 0 \tag{25}$$

$$\vdots$$

$$\Delta\psi^{(N_c)}(i,j) = 0 \tag{26}$$

The figure $T_n$ defined therefrom is a set of lattice sites on a two-dimensional lattice, and respective lattice sites are classified into $N_c$ species. That is,

$$T_n = \bigcup_{j=1}^{N_c} Q_n^{(j)} \tag{27}$$

and respective species are exclusive from each other. That is,

$$Q_n^{(j)} \bigcap Q_n^{(k)} = \emptyset \text{ if } j \neq k \tag{28}$$

$Q_0^{(k)}$ consists of a single lattice site $(i_{\text{ini}}^{(k)}, j_{\text{ini}}^{(k)})$ exclusively, and $T_{n+1}$ is created by sequentially adding one lattice site to $T_n$ by the following rule. First, Equation (23) is solved under the boundary conditions:

$$\phi(i,j) = 0 \quad \text{when} \quad (i,j) \longrightarrow \infty \tag{29}$$

$$\phi(i,j) = 1 \quad \text{when} \quad (i,j) \in T_n \tag{30}$$

and potential of each lattice site is determined. Further, Equations (24) through (26) are solved under the boundary conditions:

$$\psi^{(k)}(i,j) = \psi_\infty \quad \text{when} \quad (i,j) \longrightarrow \infty \tag{31}$$

$$\psi^{(k)}(i,j) = 1 \quad \text{when} \quad (i,j) \in Q_n^{(k)} \tag{32}$$

$$\psi^{(k)}(i,j) = -1 \quad \text{when} \quad (i,j) \in Q_n^{(l)} \ (k \neq l) \tag{33}$$

and $\psi^{(k)}(i,j)$ is determined. The lattice site to be added to $T_n$ to form $T_{n+1}$ is not included in $T_n$, and it is selected from a set $U_n^{(k)}$ of lattice sites closest to $Q_n^{(k)}$.

The number of lattice sites contained in $U_n^{(k)}$ is written as $N_n^{(k)}$. That is, the lattice site to be added to $T_n$ is selected from the following set:

$$U_n = \bigcup_{k=1}^{N_c} U_n^{(k)} \qquad (34)$$

and the number of lattice sites contained in the set, i.e. the number of candidates, is:

$$N_n = \sum_{k=1}^{N_c} N_n^{(k)} \qquad (35)$$

For each site $(i_m^{(k)}, j_m^{(k)})$ contained ir $U_n^{(k)}$, intensity of its electric field is defined as:

$$E_m^{(k)}(\alpha,\beta) = |\phi(i_m^{(k)}, j_m^{(k)}) - 1|^\alpha \times |\psi^{(k)}(i_m^{(k)}, j_m^{(k)}) - 1|^\beta \qquad (36)$$

The probability that $(i_m^{(k)}, j_m^{(k)})$ in $U_n$ is selected is proportional to intensity of its electric field $E_m^{(k)}(\alpha,\beta)$. That is, the probability is:

$$p_m^{(k)}(\alpha,\beta) = \frac{1}{\Delta} E_m^{(k)}(\alpha,\beta) \qquad (37)$$

$$\Delta = \sum_{k=1}^{N_c} \sum_{j=1}^{N_n^{(k)}} E_j^{(k)}(\alpha,\beta) \qquad (38)$$

By repeating the above-mentioned procedures, $T_n$ is formed progressively.

In the above model, the model explained in (2) is

expanded in the portion of the boundary condition $\psi^{(k)}(i,j)=\psi_{\infty}$ of $\psi^{(k)}(i,j)$ . That is, by limitation of $\psi_{\infty}=0$, the above model results in the model of (2).

Explained below is a specific example of the method for fabricating a neural network based on the model in (3) above. Results of simulations are shown in Figs. 8 through 14. In these simulations, $(\alpha, \beta)=(0.5, 1.0)$ was used, and 3000-step growth from three sites was conducted. Fig. 8 shows a case of growth under the boundary condition of $\psi_{\infty}=0$, and it is the same as (2) above. $\psi_{\infty}=-1$ was used in Fig. 9, $\psi_{\infty}=-0.6$ was used in Fig. 10, and $\psi_{\infty}=-0.2$ was used in Fig. 11.

In case that $\psi_{\infty}$ is negative, the potential difference between fractal figures belonging to species other than itself and a site at infinity becomes smaller, and the interaction among fractal figures becomes weaker. On the other hand, Figs. 12 through 14 show those in which $\psi_{\infty}$ is a positive value. $\psi_{\infty}=0$ was used in Fig. 12, $\psi_{\infty}=0.6$ was used in Fig. 13, and $\psi_{\infty}=0.2$ was used in Fig. 14.

In case of $\psi_{\infty}>0$, in contrast, interaction among fractal figures becomes stronger, and a shape massed more densely is obtained.

(4) Extended interacting fractals introducing anisotropy

Extended interacting fractals introducing anisotropy, i.e. a coupled-fractal network, are defined below. As an example, fractals made up of $N_c$ species are taken on a tetragonal lattice S in a two-dimensional

space. Regarding S as an anisotropic field, an anisotropic parameter tensor $M=(m_{\mu,\nu})$, $L=(l_{\mu,\nu})$ is introduced here. A scalar potential field $\phi_M(i, j)$ is defined on a lattice site $(i, j)\in S$, and this is called a potential. Then, $\psi_L^{(1)}(i,j)$, $\psi_L^{(2)}(i,j)$, $\cdots$, $\psi_L^{(N_c)}(i,j)$ are also defined. They satisfy the differential equations:

$$\sum_{\mu,\nu=x,y} \frac{\partial}{\partial r_\mu} \frac{1}{m_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \phi_M(i,j) = 0 \tag{61}$$

$$\sum_{\mu,\nu=x,y} \frac{\partial}{\partial r_\mu} \frac{1}{l_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \psi_L^{(1)}(i,j) = 0 \tag{62}$$

$$\sum_{\mu,\nu=x,y} \frac{\partial}{\partial r_\mu} \frac{1}{l_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \psi_L^{(2)}(i,j) = 0 \tag{63}$$

$$\vdots$$

$$\sum_{\mu,\nu=x,y} \frac{\partial}{\partial r_\mu} \frac{1}{l_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \psi_L^{(N_c)}(i,j) = 0 \tag{64}$$

Here, $\frac{\partial}{\partial r_\mu}$ represents a difference on the lattice site, and for example,

$$\frac{\partial \phi_M(i,j)}{\partial r_x} = \frac{\phi_M(i+1,j) - \phi_M(i,j)}{(i+1) - i} \tag{65}$$

The figure $T_n$ defined therefrom is a set of lattice sites on a two-dimensional lattice, and respective lattice sites are classified into $N_c$ species. That is,

$$T_n = \bigcup_{p=1}^{N_c} Q_n^{(p)} \tag{66}$$

and respective species are exclusive from each other. That is,

$$Q_n^{(p)} \bigcap Q_n^{(q)} = \emptyset, \quad \text{if } p \neq q. \tag{67}$$

$Q_0^{(p)}$ consists of a single lattice site $(i_{\text{ini}}^{(p)}, j_{\text{ini}}^{(p)})$ exclusively, and $T_{n+1}$ is created by sequentially adding one lattice site to $T_n$ by the following rule. First, Equation (61) is solved under the boundary conditions:

$$\phi_M(i,j) = 0 \quad \text{when} \quad (i,j) \longrightarrow \infty \tag{68}$$

$$\phi_M(i,j) = 1 \quad \text{when} \quad (i,j) \in T_n \tag{69}$$

and potential of each lattice site is determined. Further, Equations (62) through (64) are solved under the boundary conditions:

$$\psi_L^{(p)}(i,j) = \psi_\infty \quad \text{when} \quad (i,j) \longrightarrow \infty \tag{70}$$

$$\psi_L^{(p)}(i,j) = 1 \quad \text{when} \quad (i,j) \in Q_n^{(p)} \tag{71}$$

$$\psi_L^{(p)}(i,j) = -1 \quad \text{when} \quad (i,j) \in Q_n^{(q)} \ (p \neq q) \tag{72}$$

and $\psi_L^{(p)}(i,j)$ is determined. The lattice site to be added to $T_n$ to form $T_{n+1}$ is not included in $T_n$, and it is selected from a set $U_n^{(p)}$ of lattice sites closest to $Q_n^{(p)}$ .

The number of lattice sites contained in $U_n^{(p)}$ is written as $N_n^{(p)}$. That is, the lattice site to be added to $T_n$ is selected from the following set:

$$U_n = \bigcup_{p=1}^{N_c} U_n^{(p)} \tag{73}$$

and the number of lattice sites contained in the set, i.e. the number of candidates, is:

$$N_n = \sum_{p=1}^{N_c} N_n^{(p)} \tag{74}$$

For each site $(i_m^{(p)}, j_m^{(p)})$ (m=1, 2, ..., $N_n^{(p)}$) contained in $U_n^{(p)}$, intensity of its electric field is defined as:

$$E_m^{(p)}(\alpha,\beta,M,L) = |\phi_M(i_m^{(p)}, j_m^{(p)}) - 1|^\alpha \times |\psi_L^{(p)}(i_m^{(p)}, j_m^{(p)}) - 1|^\beta \tag{75}$$

The probability that a site $(i_m^{(p)}, j_m^{(p)})$ in $U_n$ is selected is proportional to intensity of its electric field $E_m^{(p)}(\alpha,\beta,M,L)$. That is, the probability is:

$$P_m^{(p)}(\alpha,\beta,M,L) = \frac{1}{\Delta} E_m^{(p)}(\alpha,\beta,M,L) \tag{76}$$

$$\Delta = \sum_{p=1}^{N_c} \sum_{m=1}^{N_n^{(p)}} E_m^{(p)}(\alpha,\beta,M,L) \tag{77}$$

By repeating the above-mentioned procedures, $T_n$ is formed progressively.

The above model has been extended from (3) above as a result of introduction of anisotropic parameters in Equations (61) through (64). By limitation of $m_{\mu,\nu}=m\delta_{\mu,\nu}$, $l_{\mu,\nu}=l\delta_{\mu,\nu}$ (m, l=const.), the above model results in the model of (3).

Explained below is a specific example of the method for fabricating a neural network based on the model in (4) above. Results of simulations are shown below. First shown is how the coupled-fractal changed. For easier understanding, anisotropy is introduced in only one direction on a two-dimensional lattice (in this case, in the y-axis direction on an x-y plane. That is,

$$M=\begin{pmatrix}1 & 0\\ 0 & m\end{pmatrix},\qquad L=\begin{pmatrix}1 & 0\\ 0 & l\end{pmatrix} \tag{78}$$

While fixing the parameters as $(\alpha, \beta)=(0.5, 1.0)$ and $\psi_\infty=0$, 4000-step growth was conducted from two sites on the y-axis. Figs. 15 through 20 are coupled-fractal figures upon m=l=0.5, m=l=0.75, m=l=1.0, m=l=1.25, m=l=1.5 and m=l=2, respectively. It is appreciated from these figures that as m and l increase, the coupled-fractal figure tends to extend in the y-axis direction (growth in the y-axis direction is promoted) and that as m and l decrease, the coupled-fractal figure tends to extend in the x-axis direction (growth in the y-axis direction is restricted). It is further known from these structural changes that the number of adjacent sites among different fractal figures

changes. More specifically, in the figure shown in Figs. 15 through 17, there are no adjacent sites between every two fractal figures. However, adjacent sites gradually increase from six in Fig. 18, through 57 in Fig. 19 to 95 in Fig. 20, for example. In this manner, by changing anisotropic parameters, the coupling mode among a plurality of fractal figures can be changed. Fig. 21 shows a figure as a result of growth at different values of m=0.5 and l=2.0. It is appreciated from it that influences of the anisotropic parameter l introduced into $\psi$ are larger than influences of the anisotropic parameter m introduced into $\phi$. As readily understood from the fact that the coupling strength changes, the method by this model is not mere spatial expansion and contraction, but it is an improvement by anisotropy of growth algorithm introduced absolutely first.

(5) Extended interacting fractals introducing anisotropy in a three-dimensional space

Extended interacting fractals, i.e. a coupled-fractal network, developed from the model in (4) above and introducing anisotropy in a three-dimensional space is introduced. Fractals made up of $N_c$ species are taken on a tetragonal lattice S in a two-dimensional space. Regarding S as an anisotropic field, an anisotropic parameter tensor:

$M=(m_{\mu,\nu})$, $L=(l_{\mu,\nu})$

is introduced here. A scalar potential field $\phi_M(i, j, k)$ is defined on a lattice site $(i, j, k) \in S$, and this is called

a potential. Then, $\psi_L^{(1)}(i,j,k)$, $\psi_L^{(2)}(i,j,k)$, $\cdots$, $\psi_L^{(N_c)}(i,j,k)$ are also defined. They satisfy the differential equations:

$$\sum_{\mu,\nu=x,y,z} \frac{\partial}{\partial r_\mu} \frac{1}{m_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \phi_M(i,j,k) = 0 \tag{79}$$

$$\sum_{\mu,\nu=x,y,z} \frac{\partial}{\partial r_\mu} \frac{1}{l_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \psi_L^{(1)}(i,j,k) = 0 \tag{80}$$

$$\sum_{\mu,\nu=x,y,z} \frac{\partial}{\partial r_\mu} \frac{1}{l_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \psi_L^{(2)}(i,j,k) = 0 \tag{81}$$

$$\vdots$$

$$\sum_{\mu,\nu=x,y,z} \frac{\partial}{\partial r_\mu} \frac{1}{l_{\mu,\nu}} \frac{\partial}{\partial r_\nu} \psi_L^{(N_c)}(i,j,k) = 0 \tag{82}$$

Here, $\frac{\partial}{\partial r_\mu}$ represents a difference on the lattice site, and for example,

$$\frac{\partial \phi_M(i,j,k)}{\partial r_x} = \frac{\phi_M(i+1,j,k) - \phi_M(i,j,k)}{(i+1)-i} \tag{83}$$

The figure $T_n$ defined therefrom is a set of lattice sites on a two-dimensional lattice, and respective lattice sites are classified into $N_c$ species. That is,

$$T_n = \bigcup_{p=1}^{N_c} Q_n^{(p)} \tag{84}$$

and respective species are exclusive from each other. That is,

$$Q_n^{(p)} \bigcap Q_n^{(q)} = \emptyset, \quad \text{if } p \neq q. \tag{85}$$

$Q_0^{(p)}$ consists of a single lattice site $(i_{\mathrm{ini}}^{(p)}, j_{\mathrm{ini}}^{(p)}, k_{\mathrm{ini}}^{(p)})$ exclusively, and $T_{n+1}$ is created by sequentially adding one lattice site to $T_n$ by the following rule. First, Equation (79) is solved under the boundary conditions:

$$\phi_M(i,j,k) = 0 \quad \text{when} \quad (i,j,k) \longrightarrow \infty \tag{86}$$

$$\phi_M(i,j,k) = 1 \quad \text{when} \quad (i,j,k) \in T_n \tag{87}$$

and potential of each lattice site is determined. Further, Equations (80) through (82) are solved under the boundary conditions:

$$\psi_L^{(p)}(i,j,k) = \psi_\infty \quad \text{when} \quad (i,j,k) \longrightarrow \infty \tag{88}$$

$$\psi_L^{(p)}(i,j,k) = 1 \quad \text{when} \quad (i,j,k) \in Q_n^{(p)} \tag{89}$$

$$\psi_L^{(p)}(i,j,k) = -1 \quad \text{when} \quad (i,j,k) \in Q_n^{(q)}\ (p \neq q) \tag{90}$$

and $\psi_L^{(p)}(i,j,k)$ is determined. The lattice site to be added to $T_n$ to form $T_{n+1}$ is not included in $T_n$, and it is selected from a set $U_n^{(p)}$ of lattice sites closest to $Q_n^{(p)}$ .

The number of lattice sites contained in $U_n^{(p)}$ is written as $N_n^{(p)}$ . That is, the lattice site to be added to $T_n$ is selected from the following set:

$$U_n = \bigcup_{p=1}^{N_c} U_n^{(p)} \tag{91}$$

and the number of lattice sites contained in the set, i.e. the number of candidates, is:

$$N_n = \sum_{p=1}^{N_c} N_n^{(p)} \tag{92}$$

For each site $(i_m^{(p)}, j_m^{(p)}, k_m^{(p)})$ (m=1, 2, ..., $N_n^{(p)}$) contained in $U_n^{(p)}$, intensity of its electric field is defined as:

$$E_m^{(p)}(\alpha,\beta,M,L) = |\phi_M(i_m^{(p)}, j_m^{(p)}, k_m^{(p)}) - 1|^\alpha \times |\psi_L^{(p)}(i_m^{(p)}, j_m^{(p)}, k_m^{(p)}) - 1|^\beta \tag{93}$$

The probability that a site $(i_m^{(p)}, j_m^{(p)}, k_m^{(p)})$ in $U_n$ is selected is proportional to intensity of its electric field $E_m^{(p)}(\alpha,\beta,M,L)$. That is, the probability is:

$$P_m^{(p)}(\alpha,\beta,M,L) = \frac{1}{\Delta} E_m^{(p)}(\alpha,\beta,M,L) \tag{94}$$

$$\Delta = \sum_{p=1}^{N_c} \sum_{m=1}^{N_n^{(p)}} E_m^{(p)}(\alpha,\beta,M,L) \tag{95}$$

By repeating the above-mentioned procedures, $T_n$ is formed progressively.

Explained below is a specific example of the method for fabricating a neural network based on the model in (5) above. Results of simulations on a three-dimensional lattice are shown below. Introducing an anisotropy merely

in the z-axis direction on a three-dimensional lattice, that is, determining as:

$$M = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & m \end{pmatrix}, \qquad L = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & l \end{pmatrix} \qquad (96)$$

and fixing parameters as $(\alpha, \beta)=(0.4, 0.8)$ and $\psi_\infty=0$, 5000-step growth was conducted from three sites in an x-y plane. Figs. 22 through 26 show coupled-fractal figures upon m=l=0.02, m=l=0.1, m=l=1.0, m=l=2.0 and m=l=10, respectively. Fig. 27 shows a normal deviation s in the distribution along the z-axis direction. In Fig. 27, the abscissa shows values of m=l=x. It is appreciated from these figures that distribution in the direction introducing the anisotropy can be controlled on a three-dimensional lattice. That is, by decreasing the value of m=l=x, growth in the z-axis direction can be suppressed, and to the contrary, by increasing the value of m=l=x, growth in the z-axis direction can be promoted. Here is reviewed that the number of adjacent sites among different fractal figures can be controlled approximately. Fig. 28 is a diagram made by plotting the number N of adjacent sites under the same situation as Figs. 22 through 26, namely, under m=l=0.02, m=l=0.1, m=l=1.0, m=l=2.0 and m=l=10, taking growth steps on the abscissa. It is appreciated from Fig. 28 that as values of the parameters m and l decrease, i.e., as the growth sites extend in the x-y plane defining the start sites, the number of coupling progressively increases.

The simulation program for fabricating the neural network can be supplied in form of a recording medium that can be read through a computer.

(6) Statistical interaction in a coupled-fractal network

It is natural that fluctuation occurs in a structure made through a random process or in the processing using the structure due to the random process. The same applies to information processing in our brains. However, according to the matters having been clarified along with recent developments of the statistical physics, there is a phenomenon or a universal nature that appears in such a random system only when its statistic distribution is averaged.

In a coupled fractal network, if a row of random numbers is changed in its growth process, then the shape itself of the network to be made will change, but universal properties independent from the difference are believed to exist. One of them is the statistical interaction defined by the statistic distribution. The nature there of is clarified here.

Growth of a coupled-fractal network is characterized by two parameters ($\alpha$, $\beta$). However, in actual growth tests, various networks are formed due to random variables. A review is made for universal properties not affected by the random variables.

In the simulation made below, growth of $N_c$=2 was conducted on a two-dimensional tetragonal lattice of

201x201. The first start site that is the element of $Q_0^{(1)}$ is (185, 100), and the second start site that is the element of $Q_0^{(2)}$ is (117, 100). Regarding growth of n=800 steps, growth simulation was conducted for a different row of random numbers of M=300.

Examples of simulation results are shown in Figs. 29 through 34. $(\alpha, \beta)=(0.4, 0.6)$ was used in Fig. 29, $(\alpha, \beta)=(0.8, 0.6)$ was used in Fig. 30, $(\alpha, \beta)=(1.2, 0.6)$ was used in Fig. 31, $(\alpha, \beta)=(0.4, 1)$ was used in Fig. 32, $(\alpha, \beta)=(0.8, 1)$ was used in Fig. 33, and $(\alpha, \beta)=(1.2, 1)$ was used in Fig. 34, respectively. In each of these figures, four examples of coupled-fractal networks are shown. They were grown by using the same $(\alpha, \beta)$ and different rows of random numbers. Every four examples are different coupled-fractal network structures, but have common properties, that is, properties regulated by $(\alpha, \beta)$. One of them is the fractal property of each element fractal, and it does not rely on interaction. What is discussed here is interaction among element fractals.

Interaction among element fractals can be defined solely by using a statistic average concerning a plurality of growth executed by using different rows of random numbers because there is no way of discriminating from a single growth simulation result whether the relationship among element fractals is regulated by interaction or individual element fractals have been formed independently Therefore, interaction among element fractals occurring in the

statistic average of a number of growth simulations is called statistical interaction.

Growth of M=300 was conducted, and let each growth be distinguished from others by writing it with the suffix p as $T_n(p)$, p=1, 2, ...M. It can be written as:

$$T_n(p) = \bigcup_{k=1}^{N_c} Q_n^{(k)}(p) \qquad (101)$$

by way of the element $Q_n^{(k)}(p)$ of each coupled-fractal network. The number of elements of $Q_n^{(k)}(p)$, i.e., the number of sites where k-th species in the p-th growth simulation are grown in n steps is written here as $M_{n,k,p}$. Let the barycentric coordinates of $Q_n^{(k)}(p)$ be introduced into:

$$\mathrm{w}_n^{(k)}(p) = \frac{1}{M_{n,k,p}} \sum_{\mathbf{r} \in Q_n^{(k)}(p)} \mathbf{r} \qquad (102)$$

The sample average of barycentric coordinates is:

$$\mathrm{w}_n^{(k)} = \frac{1}{M} \sum_{p=1}^{M} \mathrm{w}_n^{(k)}(p) \qquad (103)$$

and the distance between the gravity expectation values:

$$R_n^{(k,l)} = |\mathrm{w}_n^{(k)} - \mathrm{w}_n^{(l)}| \qquad (104)$$

is a convenient quantity. Then, for the purpose of analyzing the statistic interaction, a correlation function is

introduced. It is:

$$G_n^{(k,l)} = \frac{1}{M}\sum_{p=1}^{M} \mathrm{x}_n^{(k)}(p)\cdot \mathrm{x}_n^{(l)}(p) \qquad (105)$$

where

$$\mathrm{x}_n^{(k)}(p) = \frac{1}{M_{n,k,p}} \sum_{\mathbf{r}\in Q_n^{(k)}(p)} \left(\mathbf{r} - \mathbf{w}_n^{(k)}\right) \qquad (106)$$

What is analyzed here is an example of $N_c=2$. In particular, here are computed the expectation value of the barycentric distance of first and second species, namely:

$$D(n) = R_n^{(1,2)} \qquad (107)$$

and the dimensionless quantity as the correlation intensity of the first species and the second species, namely:

$$\chi(n) = \frac{G_n^{(1,2)}}{\sqrt{G_n^{(1,1)} G_n^{(2,2)}}} \qquad (108)$$

Barycentric distance in case of $\beta=0.6$ is shown in Fig. 35, that in case of $\beta=0.8$ is shown in Fig. 36, and that in case of $\beta=1$ is shown in fig. 37, respectively. It is appreciated that the barycentric distances increase with the increase of $\alpha$, respectively. That is, since the barycentric distance always increases, it means that the coupled-fractal network grows outward. In this case, it is permitted to consider that a typical repulsive interaction is working. On the

other hand, in case that D(n) decreases with n, a condensed network is formed. In this case, it is permitted to consider that a strong attractive interaction is working.

Here is reviewed the interaction intensity $\chi(n)$. Fig. 38 shows that in case of $\beta=0.6$, Fig. 39 shows that in case of $\beta=0.8$, and Fig. 40 shows that in case of $\beta=1$. In the region of $n<100$, a large difference is not observed. This is the region where growth progresses independently, and statistical interaction among species does not affect the configuration. In the region of $100<n<200$, $\chi(n)$ maintains an approximately constant value around 0.2. Thereafter, in the region of $n>200$, statistical interaction among species depending upon $(\alpha, \beta)$ appears. It is appreciated that x decreases with an increase of $\alpha$. This can be understood more easily by giving a physical interpretation of $\chi(n)$. For example, let the specie 1 deviate to the left. Then, if the species 2 is also pulled to the left, it results in $\chi(n)>0$. That is, if $\chi(n)$ is a positive, large value, the species 2 is pulled by the species 1 and follows it. On the other hand, if $x(n)<0$, the species 2 results in growing in the opposite direction, and it can be said to be repulsive. Therefore, the interpretation that the attractive force gets weaker with an increase of $\alpha$ can be concluded to be quantitatively accurate in a statistical sense. It is appreciated that the statistical interaction is affected also by a difference of $\beta$. In Fig. 40, x changes largely in response to the change from $\alpha=0.2$ to $\alpha=1.2$, but

this change decreases with the decrease of β. In the growth model of the coupled-fractal network, β controlled the adsorption probability of the adhesive substance. It is presumed that a decrease of β weakens the dependency of the adhesive substance upon its location, and thereby decreases the influences from positions where the other species are formed.

Summarizing the foregoing discussion, in a coupled-fractal network, statistical interaction among element fractals is defined by an ensemble average of a plurality of growth tests, and the universal nature of the network is controlled by the statistical interaction.

Although the invention has been explained by way of specific examples, the invention is not limited to those embodiments, but can be changed or modified in various modes based not departing from the technical concept of the invention.

As described above, according to the invention, since fractal structures are grown from a plurality of start sites, respectively, while having them interact with each other, to form fractal structures coupled to each other, a complicated network such as neural network can be made easily in a well-controlled manner. Especially when the space for growing fractal structures has an anisotropy, the coupling mode among different fractal structures can be controlled, and therefore, complicated networks such as neural networks, having a more variety of structures, can

be made easily in a well-controlled manner.

CLAIMS

1. A method for fabricating a fractal structure characterized in growing fractal structures from a plurality of start sites, respectively, while having said fractal structures interact with each other, to form fractal structures coupled to each other.

2. The method for fabricating a fractal structure according to claim 1 wherein growth rate from a specific start site among said plurality of start sites is determined by the probability that a material reaches a portion already grown from a remote site in a diffusion process, and the probability that a growth promotion factor reaches the portion already grown from portions grown from the other start sites in a diffusion process.

3. The method for fabricating a fractal structure according to claim 2 wherein said growth rate is proportional to the product of a power function of the probability that a material reaches a portion already grown from a remote site in a diffusion process, and a power function of the probability that a growth promotion factor reaches the portion already grown from portions grown from the other start sites in a diffusion process.

4. The method for fabricating a fractal structure according to claim 2 wherein fractal property, self-similarity, complexity of the structure, or the number of coupling can be controlled substantially parametrically.

5. The method for fabricating a fractal structure according to claim 3 wherein fractal property, self-similarity, complexity of the structure, or the number of coupling can be controlled substantially parametrically.

6. The method for fabricating a fractal structure according to claim 4 wherein fractal property, self-similarity, complexity of the structure, or the number of coupling can be controlled substantially parametrically by adjusting the relative potential determining diffusion of the growth promotion factor among the respective fractal structures grown from the plurality of start sites in an appropriate relation to a site at infinity.

7. The method for fabricating a fractal structure according to claim 5 wherein fractal property, self-similarity, complexity of the structure, or the number of coupling can be controlled substantially parametrically by adjusting the relative potential determining diffusion of the growth promotion factor among the respective fractal structures grown from the plurality of start sites in an appropriate relation to a site at infinity.

8. The method for fabricating a fractal structure according to claim 1 wherein an anisotropy is introduced into a space in which said fractal structures are grown.

9. The method for fabricating a fractal structure according to claim 2 wherein diffusion coefficient in a space in which said fractal structures are grown has an anisotropy.

10. The method for fabricating a fractal structure

according to claim 8 wherein fractal property, self-similarity, complexity of the structure, or the number of coupling can be controlled substantially parametrically.

11. The method for fabricating a fractal structure according to claim 9 wherein fractal property, self-similarity, complexity of the structure, or the number of coupling can be controlled substantially parametrically.

ABSTRACT

Fractal structures are grown from a plurality of start sites. The fractal structures growing from their respective start sites progress their growth while interacting with each other to form fractal structures coupled to each other and create a neural network. Growth rate from a specific start site is determined by the probability that a material reaches a portion already grown from a remote site in a diffusion process and the probability that a growth promotion factor reaches the portion already grown from portions grown from the other start sites in the diffusion process. Anisotropy, if necessary, may be introduced into the space where the fractal structures are grown.

Fig. 1

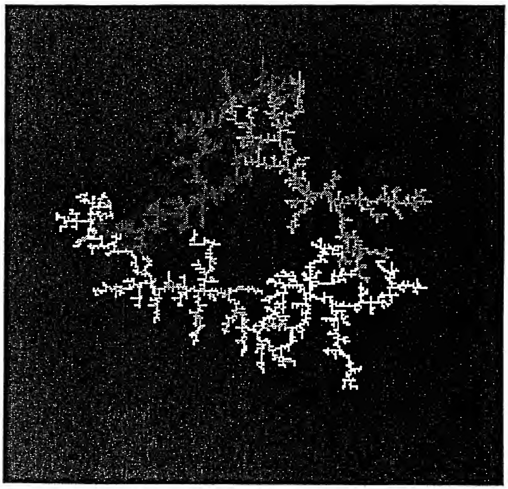


Fig. 2

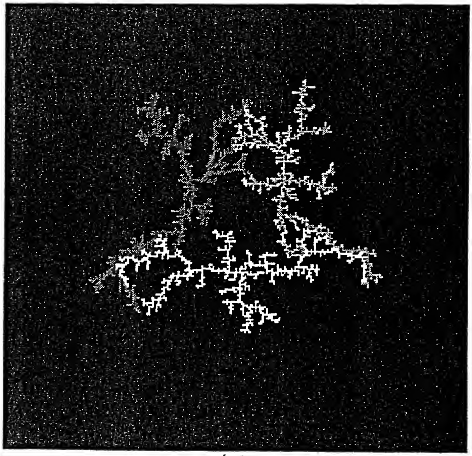
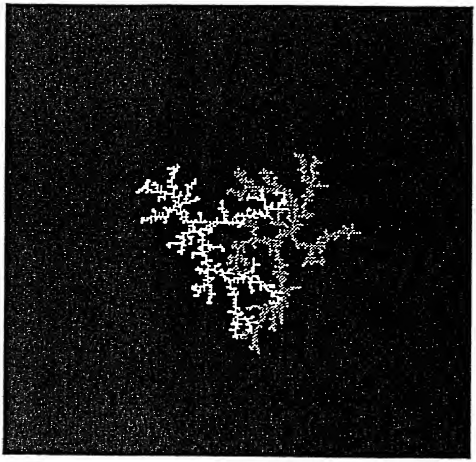
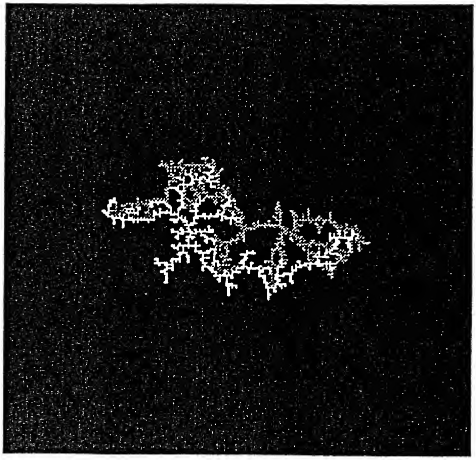


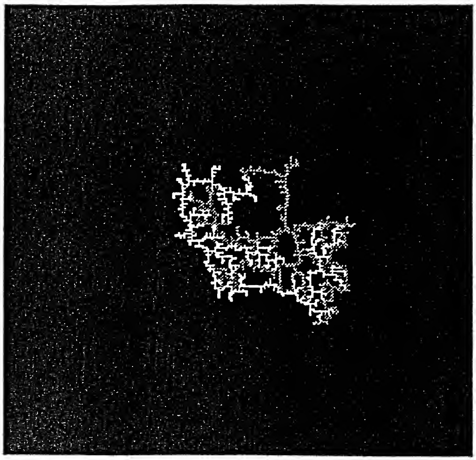
Fig. 3



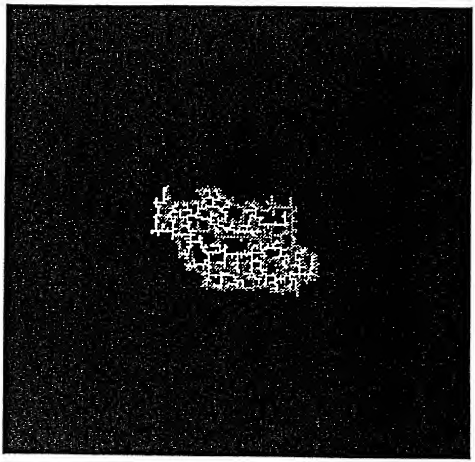
# Fig. 4



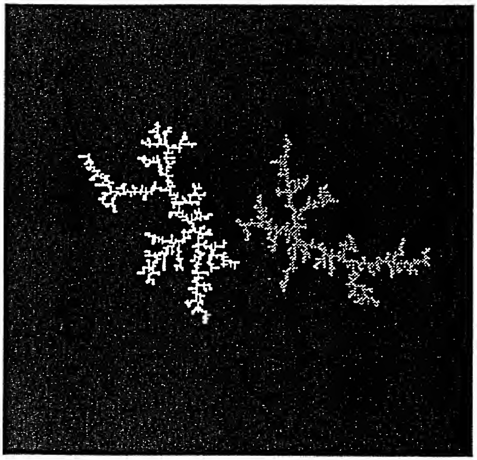
# Fig. 5



# Fig. 6

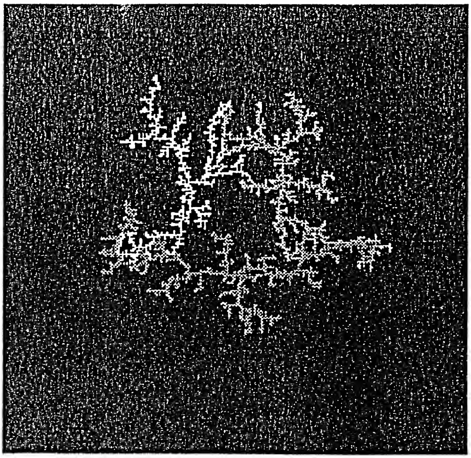


# Fig. 7



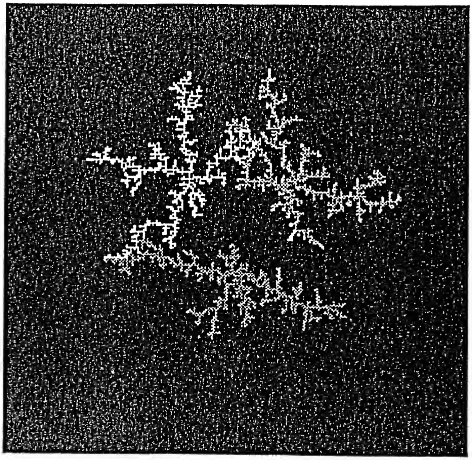
# Fig. 8

$\psi_\infty = 0$



# Fig. 9

$\psi_\infty = -1$



# Fig. 10

$\psi_\infty = -0.6$

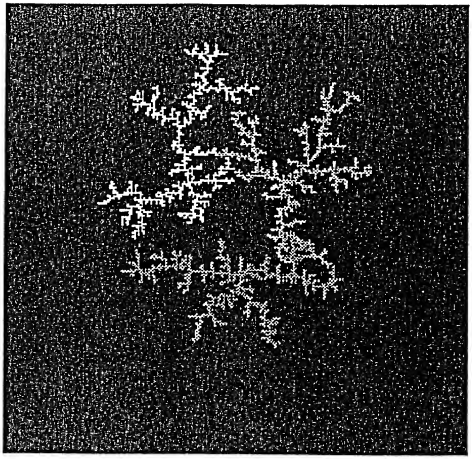
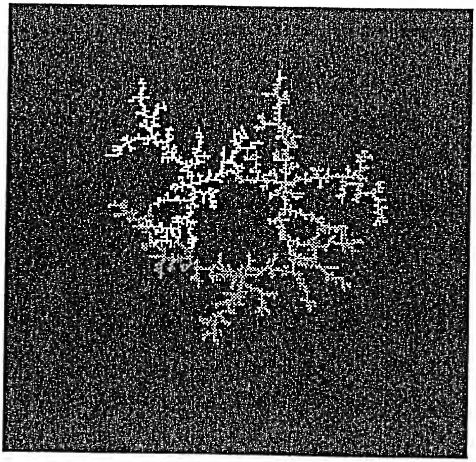


Fig. 11

$\psi_\infty = -0.2$



09/787212

# Fig. 12

$\psi_\infty = 1$

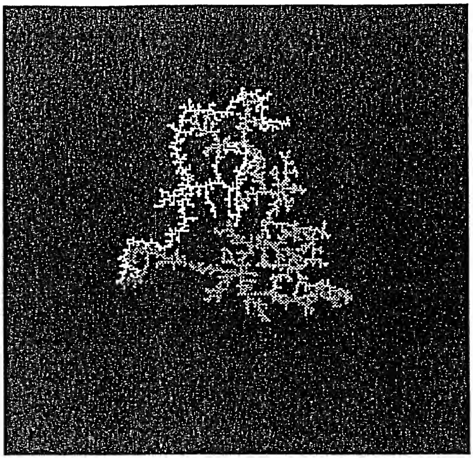
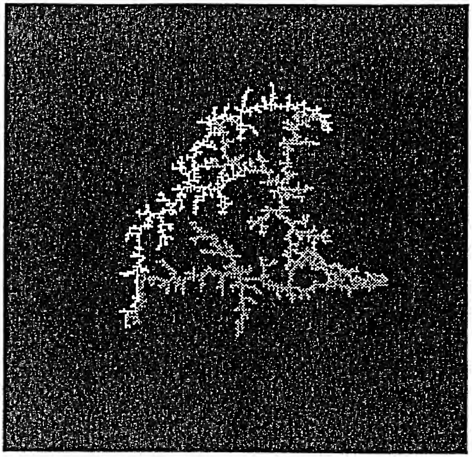


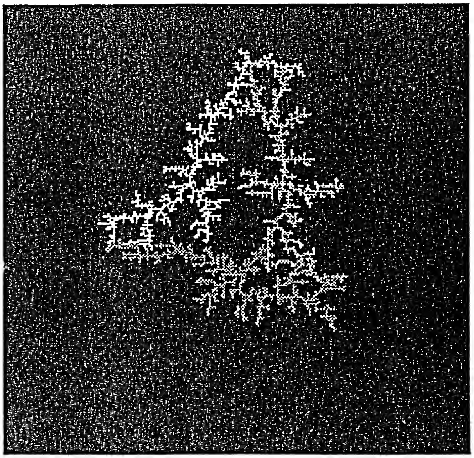
Fig. 13

$\psi_\infty = 0.6$



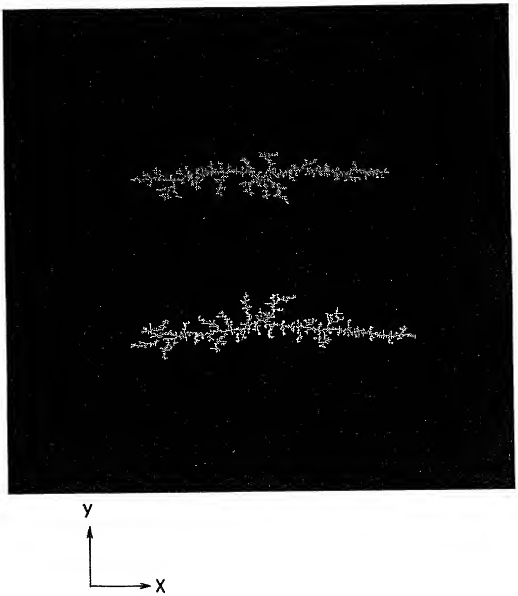
# Fig. 14

$\psi_\infty = 0.2$



# Fig. 15

m= l = 0. 5



# Fig. 16

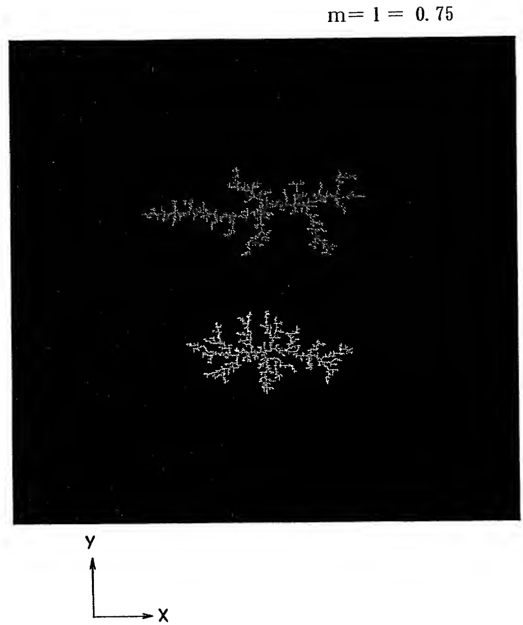
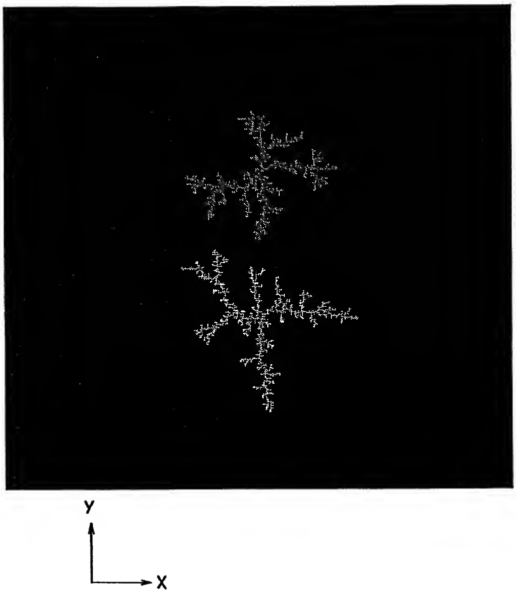


Fig. 17

m= l = 1. 0



# Fig. 18

m= l = 1. 25

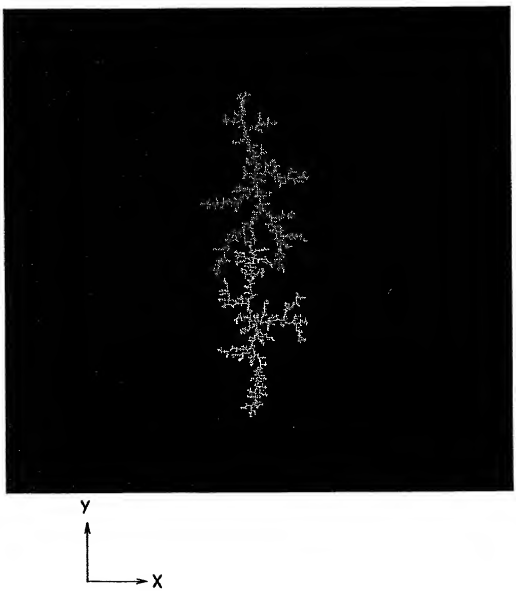


Fig. 19

m= l = 1.5

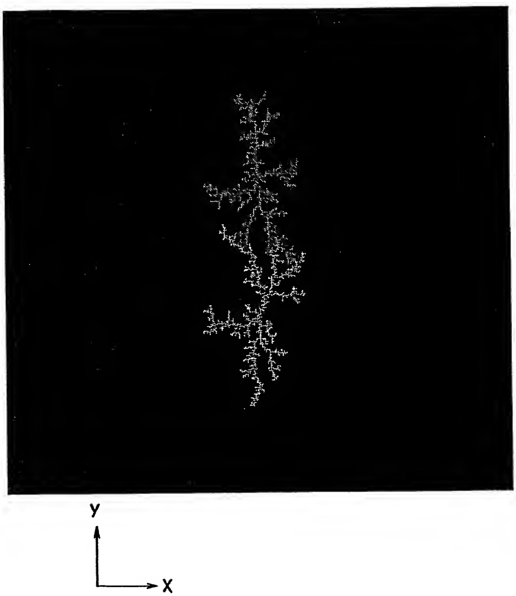
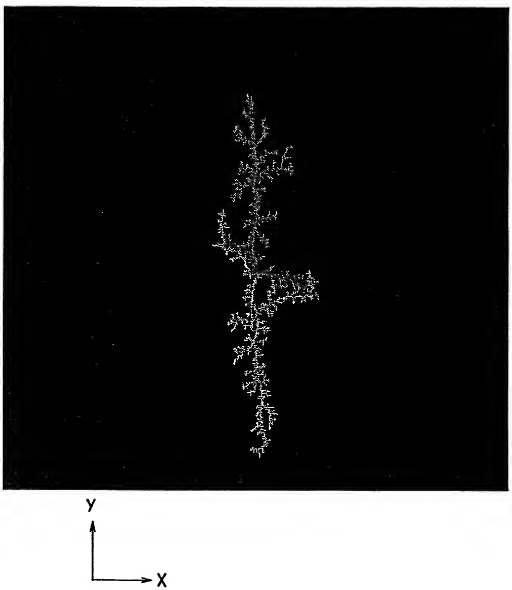
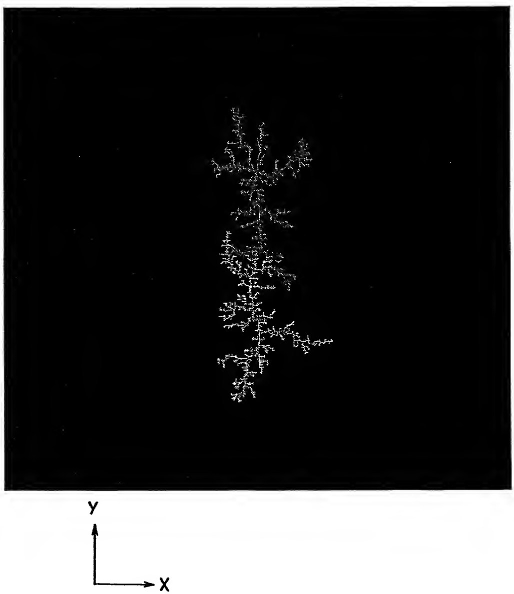


Fig. 20

m= l = 2.0



# Fig. 21



# Fig. 22

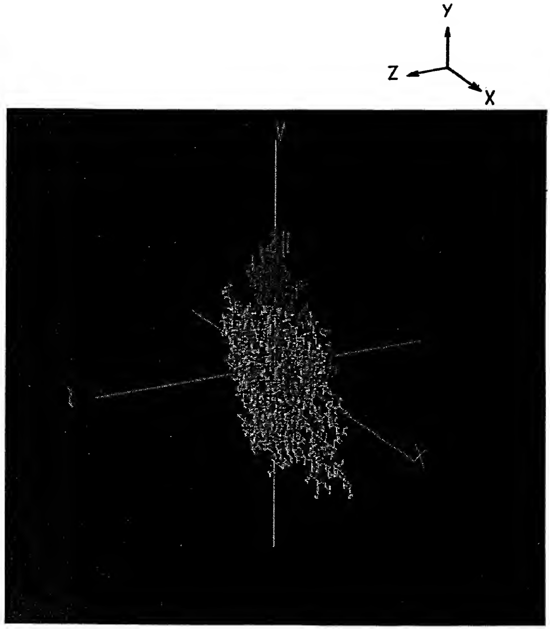


Fig. 23

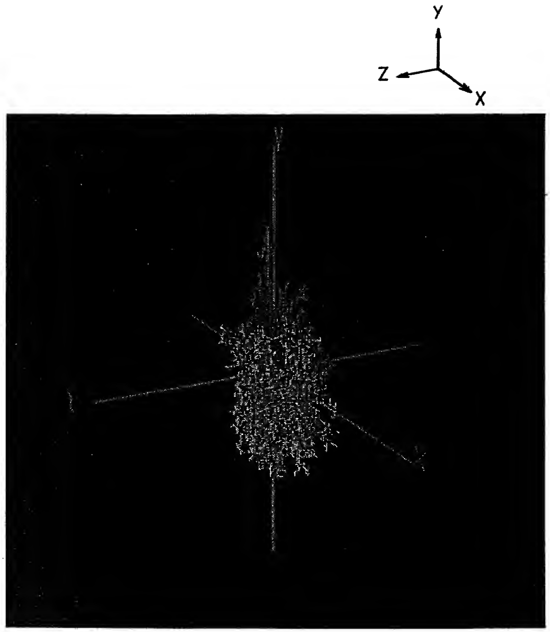


Fig. 24

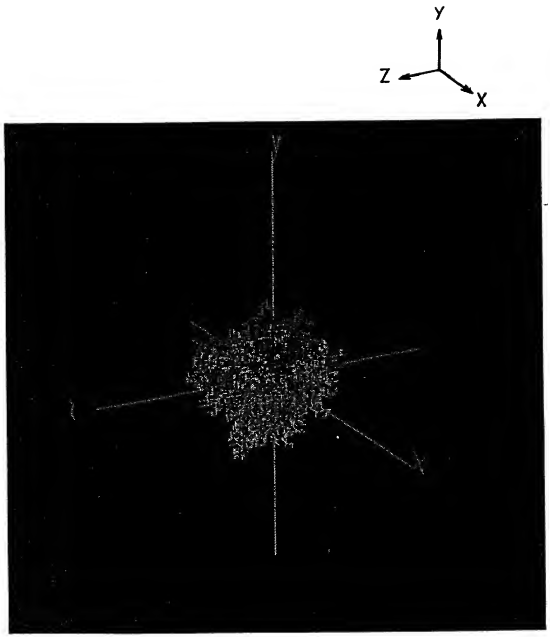
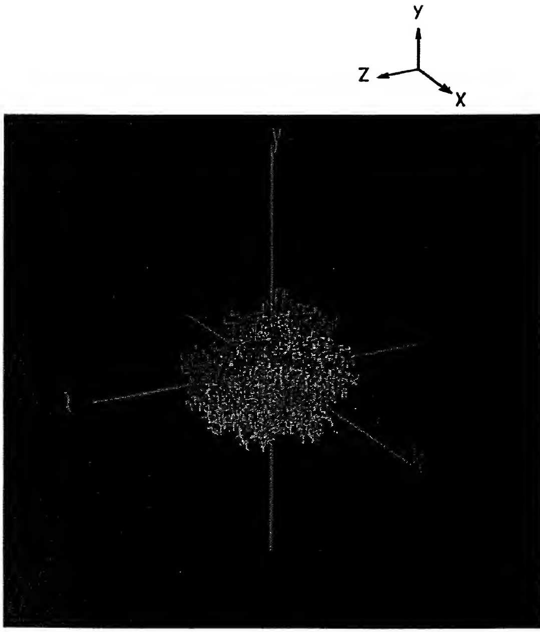


Fig. 25



# Fig. 26

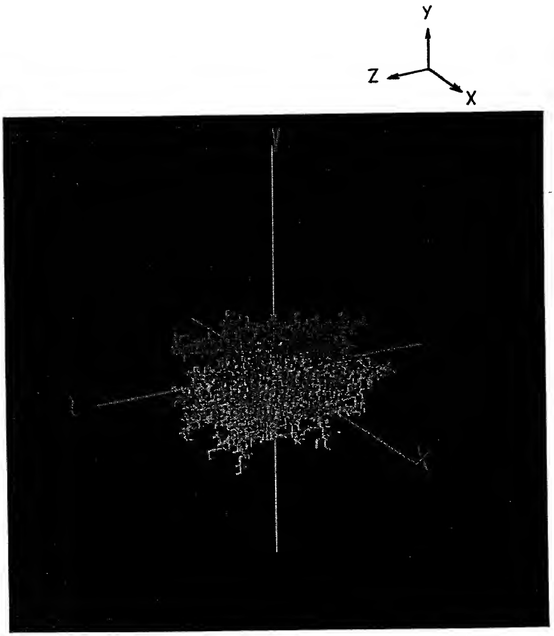
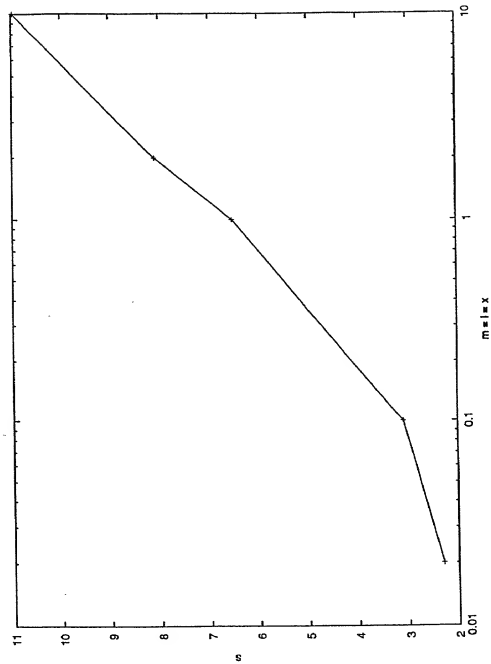
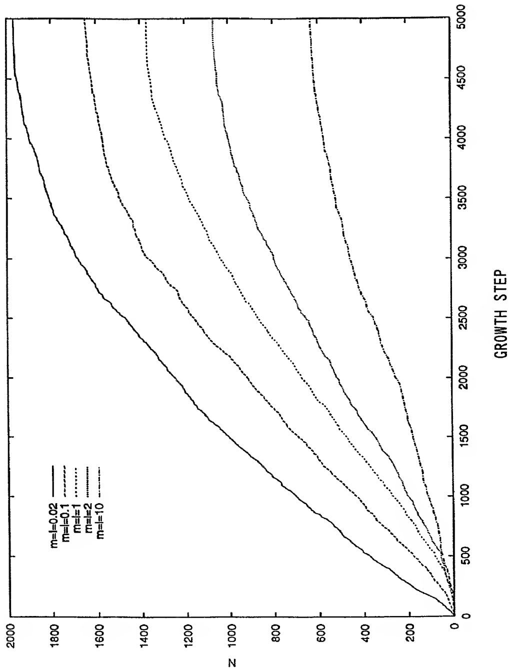


Fig. 27



# Fig. 28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m=l=1
m=l=2
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N
GROWTH STEP
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1000
1500
2000
2500
3000
3500
4000
4500
5000
200
400
600
800
1000
1200
1400
1600
1800
2000

# Fig. 29

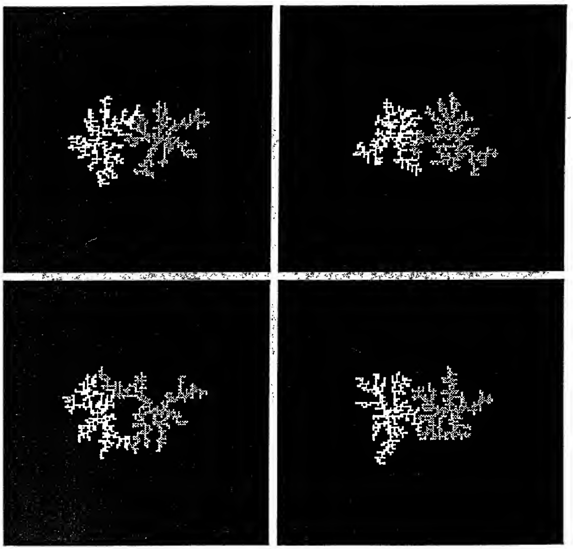


Fig. 30

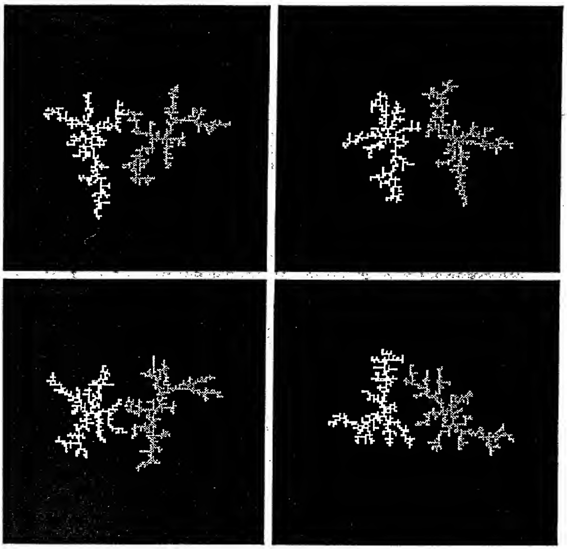


Fig. 31

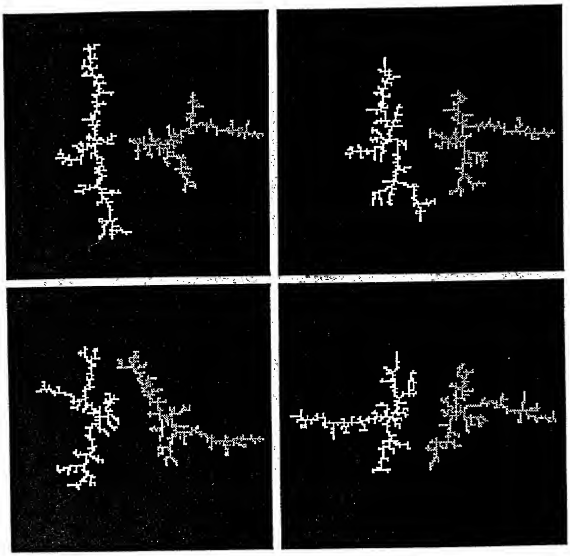
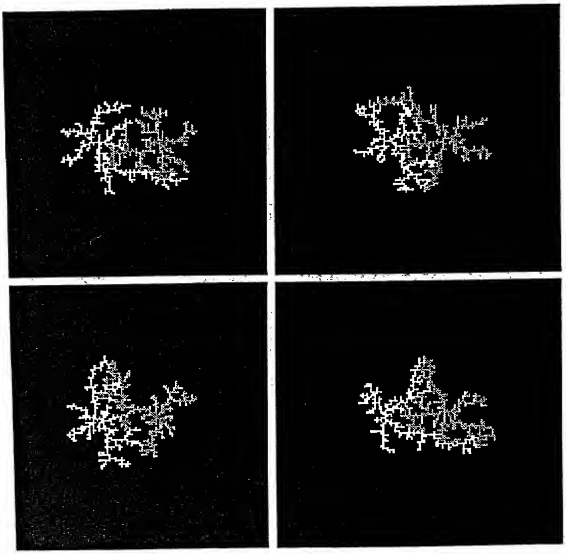
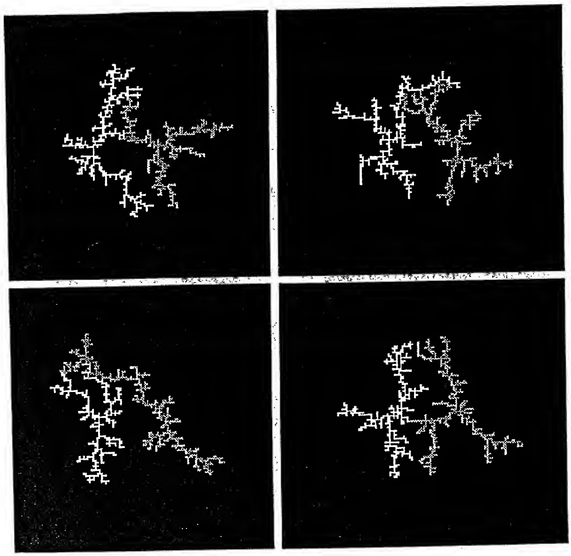


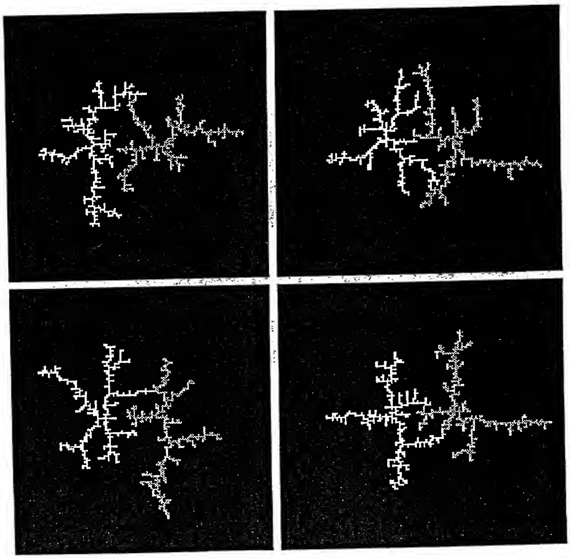
Fig. 32



# Fig. 33



# Fig. 34



09/787212

Fig. 35

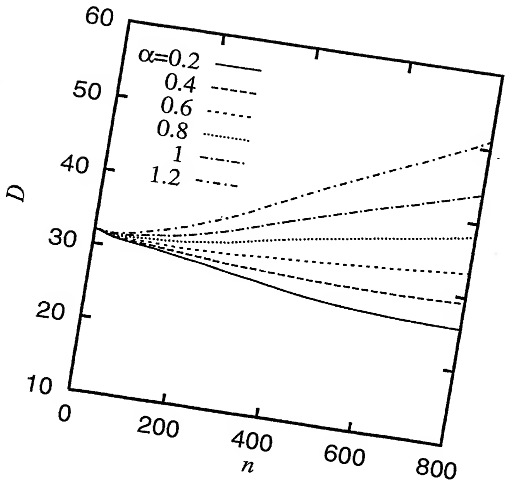
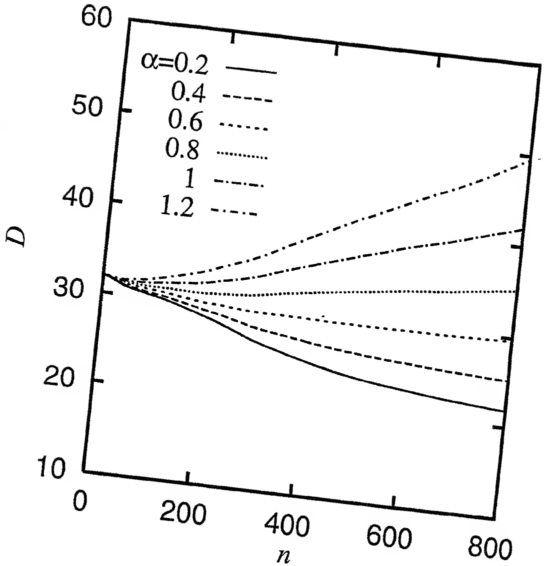
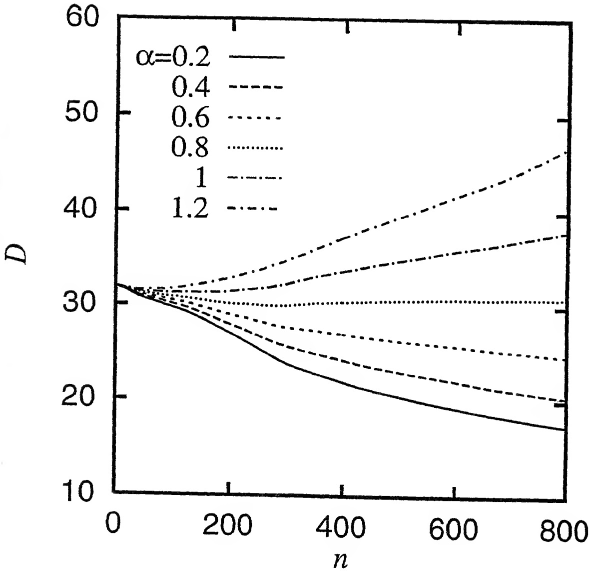


Fig. 36



# Fig. 37



# Fig. 38

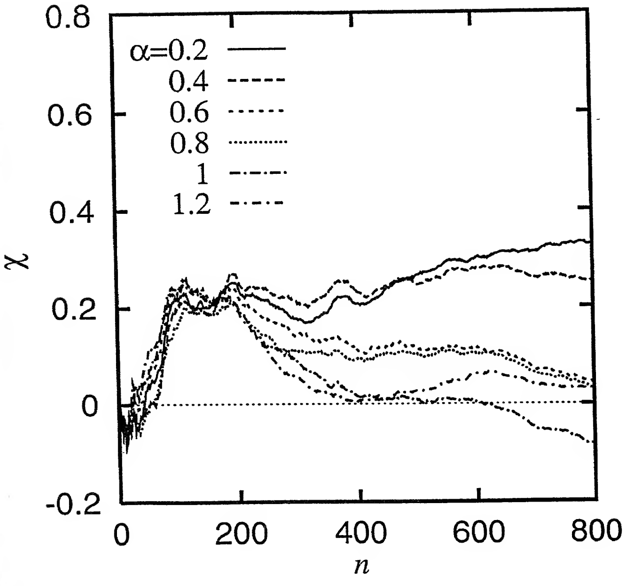


Fig. 39

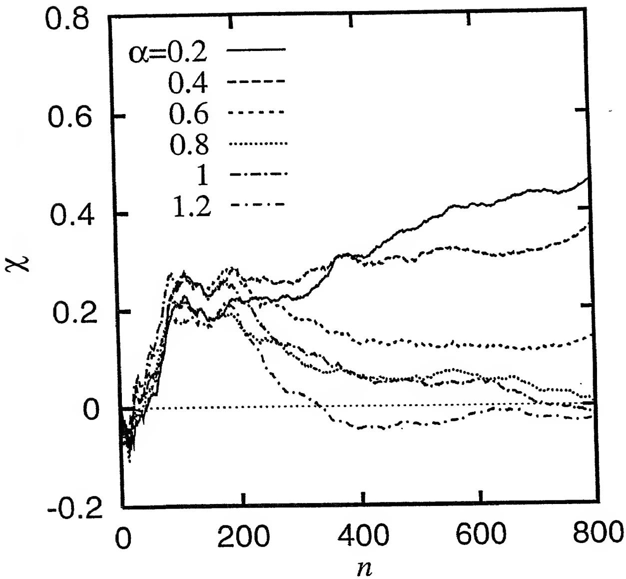
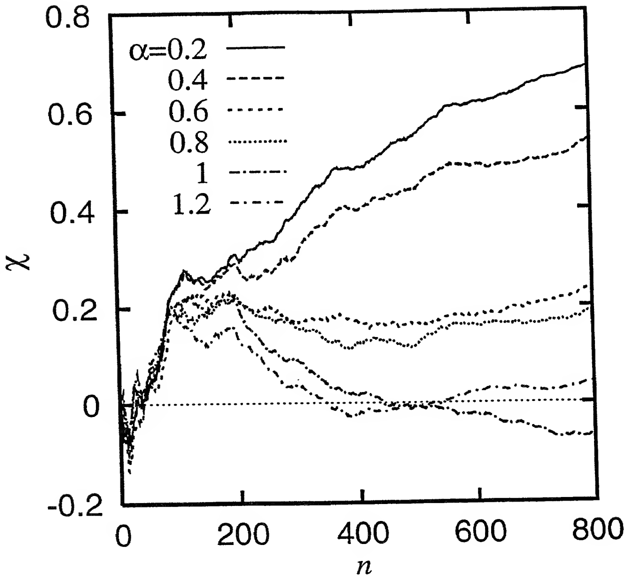


Fig. 40



S'00f006-upw

# DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION
# 特許出願宣言書及び委任状

## Japanese Language Declaration

## 日本語宣言書

**Attorney Docket No. 9704353-0014**

下記の氏名の発明者として、私は以下の通り宣言します。

As a below named inventor, I hereby declare that:

私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。

My residence, post office address and citizenship are as stated next to my name,

下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者（下記の氏名が一つの場合）もしくは最初かつ共同発明者であると（下記の名称が複数の場合）信じています。

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

**"Method for Fabricating a Fractal Structure"**

上記発明の明細書（下記の欄でx印がついていない場合は、本書に添付）は、

the specification of which is attached hereto unless the following box is checked:

☐ _月_日に提出され、米国出願番号または特許協定条約国際出願番号を__________とし、（該当する場合）__________に訂正されました。

■ was filed on March 14, 2001 as **United States Application Number** or PCT International Application Number PCT/JP00/04743 (U.S. Serial No. 09/787,212) and was amended on (if applicable)

私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

私は、連邦規則法典第３７編第１条５６項に定義されるとおり、特許資格の有無について重要な情報を開示する義務があることを認めます。

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

私は、米国法典第３５編１１９条(a)-(d)項又は３６５条(b)項に基き下記の、米国以外の国の少なくとも一ヵ国を指定している特許協力条約３６５(a)項に基ずく国際出願、又は外国での特許出願もしくは発明者証の出願についての外国優先権をここに主張するとともに、優先権を主張している、本出願の前に出願された特許または発明者証の外国出願を以下に、枠内をマークすることで、示しています。

I hereby claim foreign priority under Title 35, United States Code, Section 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate or 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)
外国での先行出願

11 200866 Japan 14 07 1999

(Number) (番号) (Country) (国名) (Day Month Year Filed) (出願年月日)

PCT/JP00/04743 Japan 14 07 2000

(Number) (番号) (Country) (国名) (Day Month Year Filed) (出願年月日)

2000-054246 Japan 29 02 2000

(Number) (Country) (Day Month Year Filed)

Priority Claimed
優先権主張なし

(Number) (Country) (Day Month Year Filed)

(Number) (Country) (Day Month Year Filed)

私は、第３５編米国法典１１９条(e)項に基いて下記の米国特許出願規定に記載された権利をここに主張いたします。

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

(Application No.) (出願番号) (Filing Date) (出願日)

(Application No.) (出願番号) (Filing Date) (出願日)

私は、下記の米国法典第３５編１２０条に基いて下記の米国特許出願に記載された権利、又は米国を指定している特許協力条約３６５条(c)に基ずく権利をここに主張します。また、本出願の各請求範囲の内容が米国法典第３５編１１２条第１項又は特許協力条約で規定された方法で先行する米国特許出願に開示されていない限り、その先行米国出願書提出日以降で本出願書の日本国内または特許協力条約国際提出日までの期間中に入手された、連邦規則法典第３７編１条５６項で定義された特許資格の有無に関する重要な情報について開示義務があることを認識しています。

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) or 365(c) of an PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

| | | |
|---|---|---|
| (Application No.)<br>(出願番号) | (Filing Date)<br>(出願日) | (Status: patented, pending, abandoned)<br>(現況：特許許可済、係属中、放棄済) |

| | | |
|---|---|---|
| Application No.)<br>(出願番号) | (Filing Date)<br>(出願日) | (Status: patented, pending, abandoned)<br>(現況：特許許可済、係属中、放棄済) |

私は、私自身の知識に基ずいて本宣言書中で私が行なう表明が真実であり、かつ私の入手した情報と私の信じるところに基ずく表明が全て真実であると信じていること、さらに故意になされた虚偽の表明及びそれと同等の行為は米国法典第18編第1001条に基ずき、罰金または拘禁、もしくはその両方により処罰されること、そしてそのような故意による虚偽の声明を行なえば、出願した、又は既に許可された特許の有効性が失われることを認識し、よってここに上記のごとく宣誓を致します。

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

委任状：　私は下記の発明者として、本出願に関する一切の手続きを米特許商標局に対して遂行する弁理士または代理人として、下記の者を指名いたします。（弁理士、または代理人の氏名及び登録番号を明記のこと）

POWER OF ATTORNEY: As a named Inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (list name and registration number)

2

David R. Metzger (Reg. No. 32,919), Joseph A. Mahoney (Reg. No. 38,956), Howard B. Rockman (Reg. No. 22,190), Jordan A. Sigale, (Reg. No. 39,028), Michael A. Molano (Reg. No. 39,777), Michael L. Kiklis (Reg. No. 38,939), Janelle D. Strode (Reg. No. 34,738), Kevin W. Guynn (Reg. No. 29,972), Jennifer Hammond (Reg. No. 41,814), Lana Knedlik (Reg. No. 42,748), John F. Griffith (Reg No. 44,137), Marina Saito (Reg. No. 42,121), Alison P. Schwartz (Reg. No. 43,863), Christopher P. Rauch (Reg. No. 45,034), Francisco Rubio-Campos (Reg. No. 45,358), Brian J. Gill (Reg. No. 46,727) Gregory B. Gulliver, Reg. No. 44,138 and Shashank S. Upadbye, all members of the firm of Sonnenschein, Nath & Rosenthal

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Direct Telephone Calls to: (name and telephone number)

312/876-2578



**Japanese Language Declaration**

**(日本語宣言書)**

| | |
|---|---|
| 唯一または第一発明者名 | Full name of sole or first inventor: Ryuichi Ugajin |
| 発明者の署名　日付 | Inventor's signature: Ryuichi Ugajin　Date: 26 June 2001 |
| 住所 | Residence: Tokyo, Japan |
| 国籍 | Citizenship: Japan |
| 私書箱 | Post Office Address: c/o Sony Corporation, 7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo 141, Japan |

（第三以降の共同発明者についても同様に記載し、署名をすること）

| | |
|---|---|
| 第二共同発明者 | Full name of second joint inventor, if any: Yoshihiko Kuroki |
| 発明者の署名　日付 | Inventor's signature: Yoshihiko Kuroki　Date: June 26, 2001 |
| 住所 | Residence: Kanagawa, Japan |
| 国籍 | Citizenship: Japan |
| 私書箱 | Post Office Address: c/o Sony Corporation, 7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo 141, Japan |
| 第二共同発明者 | Full name of third joint inventor, if any: Akira Ishibashi |
| 発明者の署名　日付 | Inventor's signature: Akira Ishibashi　Date: 27 June 2001 |
| 住所 | Residence: Tokyo, Japan |
| 国籍 | Citizenship: Japan |
| 私書箱 | Post Office Address: c/o Sony Corporation, 7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo 141 Japan |
| 第二共同発明者 | Full name of fourth joint inventor, if any: Shintaro Hirata |
| 発明者の署名　日付 | Inventor's signature: Shintaro Hirata　Date: 2 July 2001 |
| 住所 | Residence: Kanagawa, Japan |
| 国籍 | Citizenship: Japan |
| 私書箱 | Post Office Address: c/o Sony Corporation, 7-35, Kitashinagawa 6-chome, Shinagawa-ku, Tokyo 141 Japan |

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